ACEHR 2015 Annual Report
Draft
June 8, 2015

I. Executive Summary

(This summary will be written once the Committee's recommendations are settled.)

II. Introduction

The Advisory Committee on Earthquake Hazards Reduction (ACEHR) was established in 2004 as part of the reauthorization of the National Earthquake Hazards Reduction Program (NEHRP) (Public Law 108-360). The ACEHR membership consists of non-Federal employees serving three-year terms and includes members from research and academic institutions, earthquake-related design professions, and state and local governments. ACEHR is charged with assessing trends and developments in the science and engineering of earthquake hazards reduction; the effectiveness of NEHRP in performing its statutory activities and any need to revise NEHRP; and the management, coordination, implementation, and activities of NEHRP.

This report is the legislatively mandated biennial assessment of NEHRP. It is provided to the Director of the National Institute of Standards and Technology (NIST) who, under the NEHRP authorizing legislation, also serves as the Director of the Interagency Coordinating Committee on Earthquake Hazards Reduction (ICC)[1]. The recommendations of this report are also relevant for the leadership of the four NEHRP agencies and other members of the ICC. This report builds upon earlier reports submitted for FY 2012 as a full report and for FY 2013 as a less extensive update.

Since NEHRP was first authorized in 1977, the NEHRP agencies and their stakeholders have worked collaboratively, across multiple disciplines and through interagency partnerships to develop, disseminate, and promote knowledge, tools and practices to achieve the NEHRP vision of *a nation that is earthquake resilient in public safety, economic strength, and national security* (NEHRP Strategic Plan, 2008). Over these nearly 40 years, federal funding for NEHRP authorized activities has been essential to improving our understanding of earthquake-related hazards and risks, the development of earthquake safe design and construction techniques, and improved earthquake awareness and preparedness in the U.S. and the world.

This report seeks to reinvigorate the federal investment and interest in the NEHRP Program and ensure that earthquake hazard reduction remains a federal priority. The report is structured to first offer our synopsis of important developments since NEHRP's enactment (section III) and then assess the effectiveness and needs of NEHRP (section IV). Our assessment considers future directions of NEHRP, the overall management, coordination, implementation, and activities of NEHRP through the NEHRP Program Office and the ICC, and NEHRP agency specific assessments. The Committee's assessment of new trends and developments in the science and engineering of earthquake hazards reduction is provided as an Appendix to this report.

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[1] Under Public Law 108-360, membership of the Interagency Coordinating Committee on Earthquake Hazards Reduction (ICC) shall be composed of the directors of the Federal Emergency Management Agency (FEMA); the United States Geological Survey (USGS); the National Science Foundation (NSF); the Office of Science and Technology Policy (OSTP); and the Office of Management and Budget (OMB).

III. Important Developments since NEHRP's Enactment

Much has changed in our understanding of and approaches to earthquake hazard reduction since the original enactment of the Earthquake Hazards Reduction Act in 1977 and its reauthorization in 2004. Most notably is the improved understanding of earthquake hazards, the emergence and recognition of new earthquake-related risks, substantial progress in both structural and infrastructure-related earthquake engineering and seismic design, and the shift in approaches to addressing earthquake hazards as part of community-scale and multi-hazard resilience.

The improved understanding of the earthquake hazards is reflected with the 2014 release by the U.S. Geological Survey of updated National Seismic Hazard Maps. Portions of 42 states are at risk of experiencing strong ground shaking in the typical life of a building; 16 of those states, including California, Oregon, Washington, Alaska, Hawaii, Tennessee, Missouri, and many more are at very high risk (see Figure 1). This improved understanding of seismic hazards, coupled with population growth and increasing urbanization across the country, especially along the West Coast, means that 150 million people—almost half of the U.S. population—is exposed to the risk of experiencing damaging earthquake effects within the next decades. Substantial work remains to be done to improve this understanding of seismic hazards, especially as it concerns the hazard in the central and eastern United States.

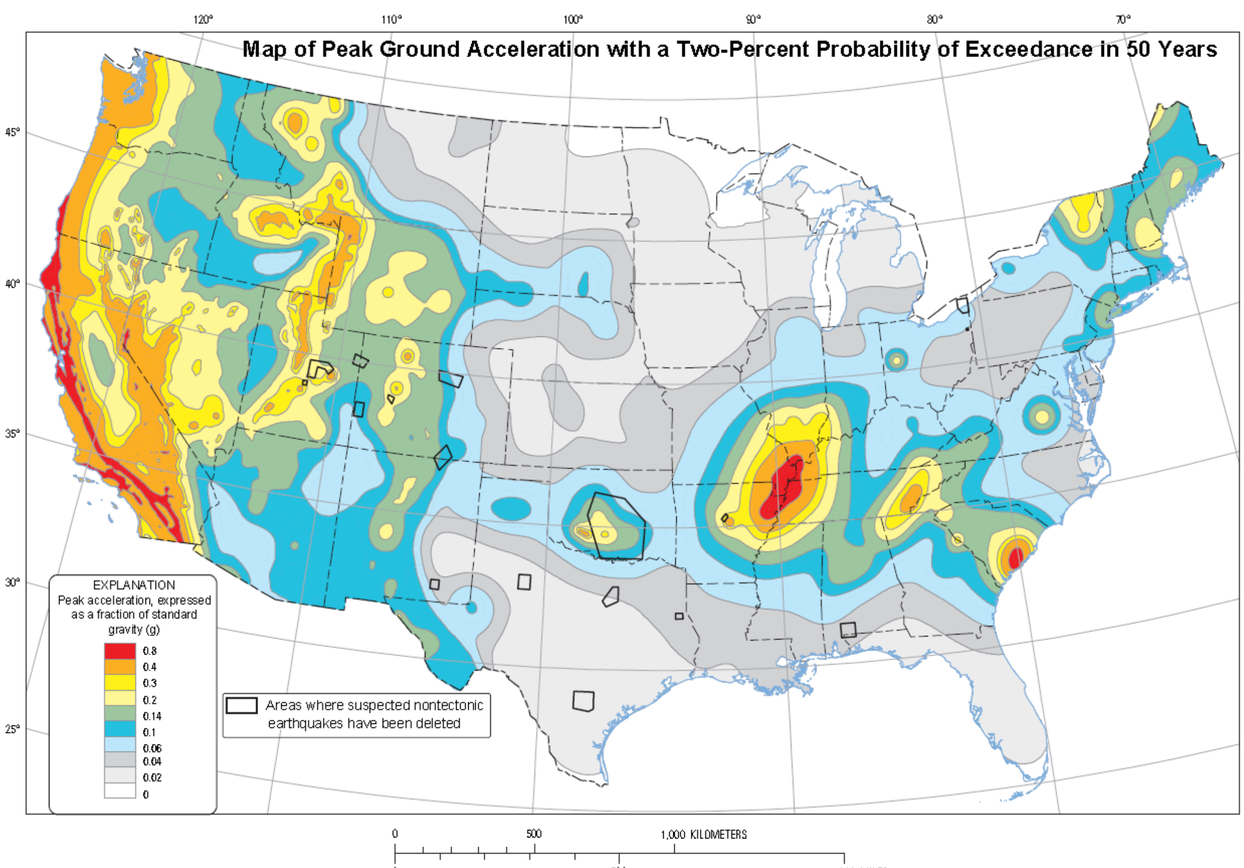

Figure 1. Map of conterminous United States showing earthquake ground motions that may be met or exceeded in the next 50 years (U.S. Geological Survey, 2014).

A newer phenomenon is the increased number of earthquakes associated with oil and gas production, particularly in the central and eastern United States. This, as noted in the 2013 ACEHR report, has raised concerns about triggered or “induced” seismicity caused by the injection of waste water generated by this and other industrial activity. While seismicity has increased throughout the region, the most dramatic increase has been in Oklahoma where, in the last decade, there has been significant oil production activity as well as large volumes of produced saltwater disposed in injection wells (Figure 2). The induced earthquakes are causing damage to buildings and infrastructure and the implications of these operations on even more substantially damaging earthquakes are not fully understood.

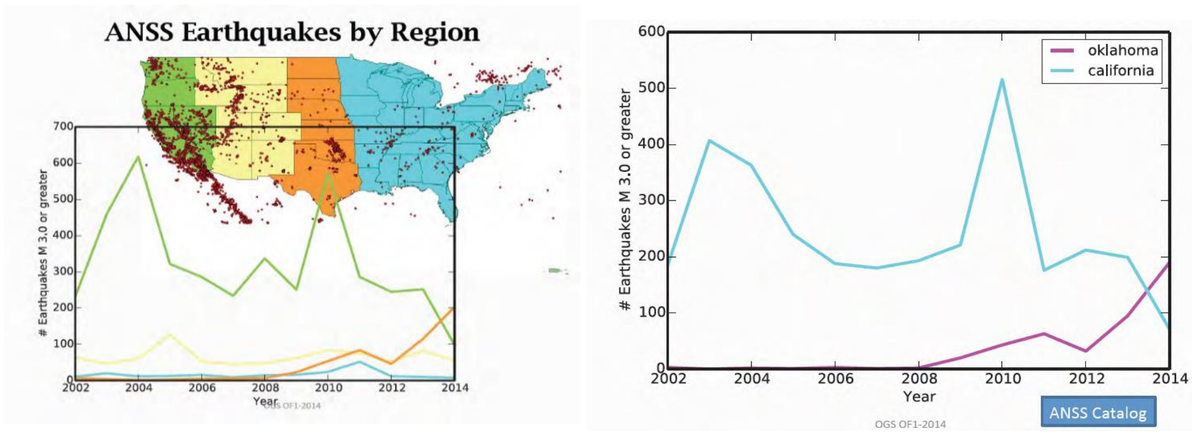

Figure 2. a) Annual rate of earthquake occurrence (magnitude 3 and larger) for different regions of the U. S. (indicated by colors). b) Comparison of the annual rate of earthquake occurrence (magnitude 3 and larger) in California (light blue) and Oklahoma (purple). Most of the increase in seismicity in the central U. S. is occurring in Oklahoma. (Oklahoma Geological Survey, Open File Report 1, 2014)

Notable advances in earthquake engineering and seismic design have been brought about because of NEHRP funding. These advances have improved the design of new buildings and have provided a basis for better seismic retrofits of existing and renovated buildings. While substantial progress has been made, notable gaps still exist in the understanding of lifeline engineering and seismic rehabilitation of many older building types.

Many of these advances have been incorporated into the seismic provisions of building codes and of other guidelines. However, two observations are important to underscore. One is that the implementation of modern seismic codes at state and local levels varies considerably. The Federal Emergency Management Agency (FEMA) estimates some 50 percent of jurisdictions in moderate to high risk regions either do not have or do not enforce such provisions. The second point is that seismic standards are based largely on a goal of preventing loss of life through collapse prevention. Many earthquake-damaged buildings may be uninhabitable until repaired or may be uneconomic to repair making it necessary to reconstruct them. As evidenced with the moderate 2014 South Napa, California earthquake, buildings constructed to the latest codes performed appropriately for the life safety standards to which they were built, but now face substantial repairs and, in some cases, full reconstruction. For larger earthquakes, especially in urbanized settings, there is considerable risk that sizable numbers of residents and businesses could be displaced with associated significant and prolonged social and economic disruptions.

A single, major earthquake in California, the Pacific Northwest, the western and central United States, and even in parts of the Atlantic seaboard could cause damages in excess of $100 to $150 billion—much larger than those caused by Hurricane Sandy and even Hurricane Katrina—and the economies could be drastically altered for years, even decades. It could also cause massive economic, political and social consequences with ripple effects across the country and the world.

The goals for earthquake risk reduction have changed substantially since the enactment of the National Earthquake Hazards Reduction Act and subsequent reauthorization. One key development has been attention within NEHRP agencies and the research community toward "multi-hazards" to include earthquake, extreme wind, and other natural hazards, with the term used by some to also include man-made hazards, such as blast and chemical releases. This attention to multi-hazards has been driven by what those at the front lines of risk reduction are asked to consider—a variety of hazards rather than a single hazard—and by some in the research community who see parallels in engineering approaches to reducing risks (e.g. earthquake, wind, and blast-related damage).

Earthquake damage also stems from multiple hazards that include ground shaking, liquefaction, permanent ground movements (fault rupture, lateral spreading, differential settlement, landslides, lurching, and other ground failures), tsunami, building collapse, chemical release, fire following earthquake, flood following earthquake, and water-borne disease. Thus, NEHRP agencies along with the greater seismic community have much to offer to the multi-hazard and community-scale resilience planning efforts, including decades of engineering and social science research, well developed analysis and design tools, and practical experience in the development of consensus-based standards and codes and the integration of seismic design into larger projects. Also, with decades of post-earthquake investigations and studies from around the world, there is considerable information on both the built environment and societal impacts associated with disasters to help advance the state-of-the-art standards related to the development of highly resilient communities.

While there are many parallels for reducing or otherwise mitigating earthquake risks, it is important to remember that at the same time there are essential earthquake-specific research issues concerning such things as earthquake source and ground shaking characterization, the seismic shaking and ground deformation effects on buildings and infrastructure systems, development of cost-effective rehabilitation solutions for buildings and infrastructure systems, and the public policy and financial mechanisms to support large-scale seismic retrofit and post-earthquake repair programs.

A second development in thinking about earthquake risk reduction is the notion of an earthquake resilient nation as a national goal. The 2012 ACEHR report embraced this goal first presented in the 2008 NEHRP Strategic Plan and also set forth in the 2011 National Research Council report, *National Earthquake Resilience: Research, Implementation, and Outreach.* That report provides a potential roadmap of national needs over the next 20 years in research, knowledge transfer, and implementation to make the country more earthquake-resilient. As discussed later in this report, a number of steps have been taken by NEHRP agencies to move in these directions. Yet, as also discussed, more must be done.

IV. Program Effectiveness and Needs

A. Future Directions for NEHRP

It has been more than 20 years since the last major damaging earthquake in the United States. Interest and support for the NEHRP program has given way to other natural disasters, like Hurricanes Sandy and Katrina, and other national priorities necessitating attention and competing for limited resources. As a result, we are extremely concerned about the long-term ramifications of the delayed reauthorization of the National Earthquake Hazards Reduction Program Act and continued under-investment in the NEHRP program. Achieving national seismic resilience requires ongoing and sustained investments in seismic monitoring and engineering research, public education and awareness about earthquake hazards, seismic code adoption and implementation for new and existing buildings and infrastructure systems, and leadership at the federal level to ensure that there is a continuum of seismic expertise for generations to come. We fear that federal policymakers, both within Congress and the Executive branch, as well as the public believe that our nation has largely solved its earthquake problem. Nothing could be further from the truth.

Recommendation 1

Nearly 40 years have passed since the enactment of the Earthquake Hazards Reduction Act (PL 95-124) that established NEHRP. It is time to conduct a fundamental assessment of where we are as a nation with respect to earthquake risk reduction, and the extent to which states, localities, tribes, and the private sector are taking steps to address seismic vulnerability in the built environment and infrastructure systems. The emphasis should be on a detailed national and regional snapshot of seismic resilience of the nation and relevant states, cities, and other entities in various regions.

The NEHRP authorization expired in 2009 with activities since then continued through individual agency appropriations processes. This Committee believes that the direction for the Program needs to be re-established first with a fundamental assessment of the nation's earthquake risk reduction progress to date. Much evidence suggests that there is a sizeable implementation deficit when it comes to achieving earthquake resilience in the nation. As advances in earth sciences have identified larger portions of the nation with significant seismic hazards, we are faced with a number of seismic-prone states and localities that either do not have or do not enforce building codes with seismic provisions. Relatively few jurisdictions in areas with moderate to high seismic hazards have programs for addressing existing unreinforced masonry, pre-1980 non-ductile concrete buildings, and other vulnerable building types used as hospitals, schools, offices, and apartments. Data for conducting local level seismic hazard assessments and implementing appropriate hazard-based land use policy are inconsistent or non-existent in many parts of the U.S. Additionally, there appears to be inconsistent attention to seismic vulnerability among public and private entities that own and manage infrastructure systems. The outreach programs supported by the NEHRP agencies are the means of disseminating practical information and training that is crucial to inform and empower our at-risk communities. But, these have often fallen short in reaching the diverse constituencies given funding limitations. This implementation deficit is the Achilles heel of earthquake risk reduction and needs to be recognized as such. This assessment should be performed either prior to or as part of a new NEHRP authorization, which has been discussed recently within some of the relevant Congressional Committees. ACEHR should be involved in helping to define the specifications for this assessment.

Recommendation 2

It is essential that a new authorization and funding levels for NEHRP reflect and build upon the developments noted above since the enactment in 1977 and the 2004 reauthorization of NEHRP. These include renewed consideration of earthquake hazards in the central and eastern United States, greater attention to the vulnerability of existing buildings, renewed emphasis on the implementation of seismic provisions,

and a recasting of the earthquake hazard reduction effort as one of improving the nation's resilience to earthquake hazards.

ACEHR believes a reauthorization of the NEHRP program needs to consider how the vision and focus of the Program can maintain its foundational emphasis on earthquake hazards and seismic design for the built environment and also provide an expanded emphasis on infrastructure, social, and economic dimensions of community seismic resilience. ACEHR remains convinced that for NEHRP to be effective and achieve the Act's vision of an earthquake resilient nation, considerably higher funding levels are needed. The costing and program activities of the 2011 NRC report, *National Earthquake Resilience: Research, Implementation, and Outreach,* provides a starting point for future reauthorization language.

Core technological interests of the Program need to be updated to consider advances in remote sensing, computing and data archiving, and social networking and to also consider the current status and future versions of NEHRP- mandated and developed technologies and operations, namely the Advanced National Seismic Research and Monitoring System (ANSS), the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) and the Global Seismographic Network. An enhanced emphasis on resilience will also require expanded roles and emphases of the current member agencies, or the addition of new agencies to the program membership.

B. Management, Coordination and Implementation of NEHRP

B1. NEHRP Program Office

Since ACEHR's last reports in 2012 and 2013, the NEHRP Office housed in NIST has continued to work collaboratively with the other NEHRP agencies to implement the "*Strategic Plan for the National Earthquake Hazards Reduction Program: Fiscal Years 2009-2013*" as well as elements of the NEHRP-commission roadmap for achieving national earthquake resilience developed by the National Research Council (2011) *National Earthquake Resilience: Research, Implementation, and Outreach*. There has been strong coordination on building and infrastructure standards and mitigation-related work among program directors of NIST and FEMA as well as seismic instrumentation between the U.S. Geological Survey (USGS) and the National Science Foundation (NSF). Also during this timeframe, we note that the NEHRP Office and NIST funded a study to update the federal post-earthquake investigation strategy (NIST 2013a), the development of a roadmap for earthquake risk reduction in buildings (NIST 2013b), and development of a roadmap for achieving earthquake resilient lifelines [2](NIST 2014)—a specific task called for in the NRC report. We applaud and encourage the focus on infrastructure systems and the proposed renewed emphasis on existing buildings.

ACEHR recognizes that without the strong commitment and financial support from NIST, the NEHRP Office would have been far less effective in its leadership role. However, the Committee remains extremely concerned about the limited resources allocated for the NEHRP Office. NIST has been carrying out NEHRP lead-agency responsibilities for nearly a decade without increased funding.

The Committee is also concerned about the repositioning of the NEHRP Office within the NIST Engineering Laboratory over the past two years. The NEHRP legislation calls for the directors of the four

[2] Lifelines is a term often used in the earthquake engineering field and referring more specifically to those infrastructure systems that are critical to societal functioning, such as power, water, sanitation, telecommunications, and fuel.

member agencies to serve on the ICC. With recent reorganizations, the NEHRP Program Director is now much farther removed from the NIST Director, and even more so than other NEHRP program officers at other member agencies. The Committee is concerned that this places the NEHRP Program Director and NEHRP Office at a serious disadvantage in coordinating and engaging with other agencies on program-related matters and in advocating for program-related budget and needs within NIST.

B2. Interagency Coordinating Committee on Earthquake Hazards Reduction (ICC)

We find most NEHRP agencies are working very hard to do more with less, while the Program continues to lack sufficient resources as well as, in some instances, crucial internal agency support to achieve the NEHRP vision. That vision entailed a shared commitment to carry out the NEHRP Strategic Plan with a broader 18-task roadmap for achieving national earthquake resilience outlined in the NRC's 2011 report. One path for addressing the implementation deficit is what has been endorsed in the prior ACEHR reports – full funding of the NEHRP Strategic Plan and the NRC report. For more than a decade, federal funding levels for the NEHRP Program have hovered around \$120 to \$125 million annually and, as this Committee has noted in prior reports, the budget for some critical areas of earthquake hazards reduction—most notably implementation activities assigned to FEMA—have decreased significantly over that timeframe. The NRC report estimates that the cost to carry out the 18-task program of research and outreach would total about \$307 million a year during the first five years of task implementation which are far beyond NEHRP's current funding levels.

Although it is unlikely that full funding will be forthcoming from Congress, it is important to underscore the need for this funding to the ICC as a reminder of what needs to be accomplished. We fully endorse prior recommendations by ACEHR and ask the NEHRP agencies to work internally to secure full funding of the NEHRP Strategic Plan and the NRC report. Should circumstances change, as would happen with a catastrophic earthquake in this country, there may be more interest in funding this blueprint for improving earthquake resilience.

Recommendation 1

ACEHR recommends that the ICC be revitalized as a mechanism for advancing NEHRP within the respective agencies. This will require renewed consideration by the leadership of the ICC about the future of NEHRP and how their agencies can assist in moving the Program ahead along with stronger articulation of how NEHRP activities relate to other priorities and agendas within the respective agencies.

The ICC is the body that is intended to provide the senior political level of leadership to higher management within their respective agencies. The NEHRP legislation requires that the ICC meet three times a year. However, the ICC has apparently not met in more than two years. ACEHR is concerned that, as a result of this, much of NEHRP'S senior agency management as well as Congress and the White House Office of Science, Technology and Policy, may not understand the challenges that the Program faces, particularly the financial problems brought about by sequestration and other budgetary cuts. As this and prior ACEHR reports make clear, the needs are extensive in order for substantial progress to be made in reaching the goals of NEHRP.

In prior decades, the ICC members played significant roles in advancing commitments of NEHRP agencies and working collectively on budget issues and policy decisions about future directions. This provided a mechanism for addressing the interdependencies of the Program agencies and was a basis for desired additional funding for each of the agencies in the aftermaths of 1989 Loma Prieta and 1994

Northridge earthquakes. Should we experience a major U.S. earthquake today, ACEHR is concerned that the ICC will not be prepared to guide the new level of attention inevitably demanded of the Program in ways that build upon the many developments and directions noted in this report.

To make up for this void in higher-level coordination, the program managers at each NEHRP agency have formed a mid-level coordinating group, which has met on an ad hoc basis with a variety of levels of personnel participating. While this is an admirable undertaking, such a working group cannot replace the ICC and cannot deliver the overall vision and direction that the ICC provides.

Implementation of the recommendations included in this report requires close collaboration and action on the part of all four agencies. Some may require a mutual commitment of resources and may result in significant changes in the current direction of NEHRP. The Committee hopes this report will be a stimulus for reengaging the ICC membership to bring them together for a substantive discussion of the report and its recommendations. This initial meeting could be followed by a series of meetings focused on topics such as how prepared, as a nation, we are for a large damaging earthquake, status and interdependencies of various NEHRP programs and initiatives, impacts of new and emerging issues and related initiatives, such as resilience and, of course, budgets.

ACEHR also asks the ICC to consider how the NEHRP program can develop more synergistic collaboration and funding opportunities to fulfill the NEHRP mission and work plans defined in the NEHRP Strategic Plan and the 2011 NRC report, as part of the broader multi-hazard community resilience momentum. A complementary path for addressing the implementation deficit rests on leveraging earthquake-related resilience efforts with other efforts to improve the nation's resilience for a range of natural and man-made risks that include catastrophic natural disasters. But, such leveraging may require a re-orientation of some existing NEHRP efforts to involve more than coordination with other resilience programs. Earthquake resilience should be a notable component of programs like the National Infrastructure Protection Program and the NIST Community Disaster Resilience program. At the same time, the Committee is concerned about maintaining an earthquake hazards reduction focus at NSF given its decision to move to a new multi-hazard engineering research program, NIST given the NEHRP Program's office integration into the NIST Community Disaster Resilience program, and at FEMA with the earthquake program's staff multi-hazard responsibilities within the FEMA Mitigation Directorate.

Recommendation 2

> **ACEHR recommends that the ICC conduct a review of the status of core operational elements authorized and funded under the NEHRP program with attention to those elements that have been dropped, those that have been cutback, and those that have been expanded or added.**

This recommendation stems from two concerns. One is that some mandated elements, discussed below, have been dropped. A second concern is that the growing emphasis on multi-hazard resilience may be channeling both Program focus and funding away from earthquake hazards and that this, in particular, may be adversely impacting core operational activities funded or developed under NEHRP.

For example, in 2013, the National Science Foundation decided not to make another five-year award for the George E. Brown Network for Earthquake Engineering Simulation Operations for FY2015-FY2019 (known as NEES2 Operations). Instead, it launched a new multi-hazard engineering research program, NHERI, in early 2014 and is parsing its support for the former NEES operations into a series of up to 10 separate awards for a network coordination office, experimental facilities, cyberinfrastructure, and computational modeling and simulation tools for both earthquake engineering and wind engineering research. This decision is contradictory to this Committee's 2013 urging for continued support of the NEES infrastructure, collaboratory, and associated research at current or increased levels, and is contrary to Program activities specified in the NEHRP authorizing legislation (section 7704a2D) to develop, operate and maintain the George E. Brown Network for Earthquake Engineering Simulation Operations. Much to this Committee's dismay, the NSF has been unable to provide sufficient information on how it will ensure that funding levels and investments in earthquake hazards reduction will be maintained with this new multihazard and parsed approach to funding earthquake engineering research.

C. Federal Emergency Management Agency (FEMA)

FEMA is the primary agency within NEHRP for earthquake mitigation, including the dissemination of guidelines about seismic building practices, development of seismic provisions and other mitigation strategies, and promotion of earthquake preparedness. ACEHR finds that FEMA continues to make noteworthy contributions to NEHRP with the small number of FEMA staff assigned to these tasks working diligently to fulfill their responsibilities. FEMA takes an active role in supporting and contributing to national building codes and standards (e.g. ASCE 7, ASCE 31, and ASCE 41), produces a prodigious amount of publications and related products for both technical and non-technical audiences, including consensus-based guidance on seismic design (NEHRP provisions) and delivers a broad scope of training opportunities to states, local governments and the public. Following the 2014 South Napa Earthquake, FEMA funded studies on the performance of buildings and non-structural components (FEMA P-1024) and also developed FEMA DR-4193-RA1, *South Napa Earthquake Recovery Advisory on Repair of Earthquake Damaged Masonry Fireplace Chimneys.*

We also find that FEMA is leveraging an array of public/private partnerships, such as with the International Code Council, standard development organization, earthquake engineering membership organizations and state earthquake management to further its implementation reach. We also recognize FEMA's commitment to the annual Shakeout preparedness drills (which have taken on a national flavor and thus increasing earthquake awareness throughout the Nation) and to the development of QuakeSmart, a program for earthquake preparedness for businesses. FEMA has also demonstrated strong partnerships with NIST and the USGS, for example helping to assure the USGS information on current earthquakes is utilized and integrated into the mitigation, planning and preparedness efforts that it helps to fund.

At the same time, FEMA's critical role in implementation of risk reduction activities at the State and local levels, and translation of technical information into applicable tools for earthquake risk reduction has been hampered by a variety of factors. The single most important issue is the continued reduction of the budget for the FEMA Earthquake program and the lack of sufficient staffing, which we address further below.

The Committee supports the all-hazard approach that FEMA has embraced. However, just like floods and hurricanes, there are unique aspects of the earthquake hazards that need to be addressed and incorporated into state and local hazards planning. In addition, research supported by earthquake funding has greatly added to the technical knowledge that has led to advancements in hazard mitigation techniques and application. The Committee believes that an all-hazards approach would greatly benefit from supporting and working more closely to apply earthquake hazards reduction techniques to other hazards such as wind and landslides.

Recommendation 1

ACEHR recommends FEMA reinvest efforts into FEMA's mitigation mission and NEHRP-related implementation and outreach activities.

ACEHR recognizes the constraints of the current budget environment. However, the Committee urges FEMA management to request funding levels that will allow the agency to fully pursue its implementation role as part of a broader initiative to reinvigorate the implementation component of NEHRP. The substantial decline in FEMA's NEHRP-related funding is not due to budget cuts imposed by Congress, but by FEMA's own failure to request adequate funding to meet its NEHRP-related mandate. Since 2001, FEMA's Earthquake program budget has been reduced from approximately $18 million down to $6 to $7 million annually and FEMA's Fiscal Year 2015 budget is about $1.5 million less than the Fiscal Year 2014 budget. FEMA Headquarters currently has three full-time employee positions supporting NEHRP, down from approximately 12 positions—including the loss of two senior positions in the last year. Also, until very recently many of the Earthquake program positions in FEMA regions have been either unfilled, or only staffed part-time. ACEHR believes that these reductions have led to a serious erosion of FEMA's capability, and the impacts that they had, in developing and delivering technical advice and tools to critical earthquake constituents.

The mitigation mission of NEHRP is dramatically under-funded and FEMA's Earthquake program is significantly under-supported relative to the scale of the problem, the increasing severity and frequency of natural disasters, and the potential for a major earthquake to impact the U.S. in the near future. An earthquake will expose the erosion of State and local capability to recover, in part, because of the diversion of funding from FEMA programs. ACEHR further recommends filling the many vacant earthquake program manager positions within the FEMA regions by active recruitment, restoring cuts in salary and benefits for these positions, and fully funding all earthquake program positions.

Recommendation 2

ACEHR recommends FEMA reconsider returning to a directly-funded state-based program for earthquake hazard mitigation, planning, education and preparedness efforts and ensure its full funding.

ACEHR acknowledges FEMA re-evaluation of the current process of delivering its program of grants and assistance to states for earthquake related mitigation, planning, education, and preparedness through multi-state consortia. At the May 2013 National Earthquake Program Managers Meeting in Denver, state representatives called for a return to direct funding of the states rather than through the consortia, greater transparency in administration of the grants program, expansion of eligible projects for funding, and a long-term strategy for the grant program rather than an annual "needs list."

ACEHR believes it is important to recognize that, in some cases, the consortia are poorly equipped to serve as funding agencies and their service areas have little correspondence with FEMA's regional boundaries. Also, we encourage FEMA to reconsider the current state grant matching formula and whether it should be altered to realistically represent states abilities, and to increase the overall level of funding for the State earthquake programs that also has declined steadily over the past decade.

Recommendation 3

ACEH R recommends FEMA reinvigorate the lifeline/infrastructure seismic hazard mitigation and resilience initiative.

FEMA has scaled back its investment in the development of lifeline and infrastructure codes and standards development as well as other lifeline and infrastructure related resiliency and preparedness efforts in parallel with the reduction in NEHRP-related funding. FEMA is encouraged to initiate lifeline-related work consistent with the *Earthquake-Resilient Lifelines NEHRP Research, Development, and Implementation Roadmap (NIST GCR 14-917-33)*.

Recommendation 4

ACEHR recommends FEMA continues to invest in maintaining Hazus as a utilizable earthquake hazard mitigation tool and ensure that the tsunami module is fully integrated and functioning within the Hazus software platform.

Hazus is the primary risk modeling and scenario planning tool used by State and local governments for earthquake hazard assessment, mitigation preparedness and planning efforts. There have been no major updates or improvements to the Earthquake module in many years and the earthquake damage curves are out of date and need improvement. A tsunami module was initiated but never completed and it is critical that scenario development and risk mitigation planning for earthquakes and tsunamis be integrated and linked, especially in the coastal regions of California, Oregon, Washington, Alaska and Hawaii, where the threat of large near-shore, earthquake-generated tsunamis, like those experienced in Indonesia (2004) and Japan (2011), is very high.

Recommendation 5

ACEHR recommends FEMA facilitate the formulation of consensus standards for the development of a market-based seismic hazard grading system for buildings.

ACEHR recognizes concerns within FEMA about the development of a building rating system. Nonetheless, as recommended in past ACEHR reports, such a rating system has many merits worth continued exploration and development. More work should be undertaken in conjunction with organizations such as American National Standards Institute (ANSI) and/or the U.S. Resiliency Council (USRC) to establish consensus within the engineering community on standards to be used in grading the seismic vulnerability of buildings. Until recently, no single standard has obtained general support and acceptance in the structural engineering community. The USRC has undertaken the process of developing a universal building rating system and obtaining input from a variety of engineering sources and stakeholders. Their proposed star grading system has the goal of stimulating market forces to promote the upgrading of seismically deficient buildings. However, there are a still a number of critical issues that need to be addressed for the system to be effective, including sourcing the funds and market incentives and policy impetuses for building owners to undertake the necessary evaluations. FEMA is encouraged to establish a stakeholder's group, possibly under the auspices of ANSI, to help develop a standard for a grading system to be referenced within the building codes for both new and existing structures.

D. National Institute of Standards and Technology (NIST)

NIST is responsible for carrying out research and development to improve building codes and standards and practices for structures and infrastructure systems. This mission is of critical importance to the NEHRP program, since it is through these efforts that the NEHRP research activities are implemented in the built environment.

The NIST activities include promoting the implementation of the NEHRP research in model building codes and standards, providing resources to practicing architects and engineers that promote better design and construction practices and cost effective and affordable performance based seismic engineering. NIST also supports the efforts of national standard organizations in the development of seismic safety standards and best practices for infrastructure systems. In addition, NIST works with NSF, FEMA, and USGS on planning for earthquake engineering research.

We commend NIST for "leaning forward" on important and urgent topics to earthquake professionals. NIST, often in partnership with FEMA, currently has multiple ongoing projects related to performance-based structural design as well as programs related to the validation of specific lateral force-resisting systems and elements. Also, in the past several years, NIST has made significant strides in identifying future research needed to meet its core mission with the development of the *NIST Measurement Science R&D Roadmap: Earthquake Risk Reduction in Buildings (NIST GCR 13-917-23)* and the *Earthquake-Resilient Lifelines NEHRP Research, Development, and Implementation Roadmap (NIST GCR 14-917-33)*. These roadmaps provide specific recommendations for improving design requirements and practices for structures and infrastructure systems. Further, NIST is selecting high-priority topics identified in these roadmaps for funding and implementation, demonstrating good overall management of its research program and its charge to provide meaningful technology transfer to the practicing engineering community and further cooperation and coordination among the NEHRP agencies.

The NIST Engineering Laboratory is currently engaged in a national Community Disaster Resilience Planning program that will help to make buildings, infrastructure systems, and entire communities safer and more resilient in the face of natural and human-made hazards. We appreciate the growing synergies between the Community Disaster Resilience Planning program and the NIST NEHRP-related work, and encourage NIST to continue to identify and leverage opportunities for collaboration. At the same time, the Committee is concerned about ensuring that a focus on earthquake hazards reduction is maintained because the nation's earthquake risk is immense and there are essential earthquake-specific issues related to both new and existing structures and infrastructure systems that require sustained program investment and attention.

Recommendation 1

ACEHR recommends NIST improve the dissemination of NEHRP-related information and products to the architectural and engineering professions.

The NIST TechBrief report series, which consists of individual report volumes on a specific earthquake engineering topic, are typically concise with well-illustrated discussions that address practical problems faced by engineering design and construction practitioners. ACEHR encourages NIST to work on improving their outreach efforts with the "average" design engineers and others in the Architectural and Engineering communities. We also suggest that NIST investigate who is using their products and whether they are reaching the target audiences.

Recommendation 2

ACEHR recommends NIST develop future NEHRP-related research and development programs on infrastructure systems, geotechnical engineering, non-structural elements, and residential and industrial structures that have seismic vulnerabilities.

ACEHR encourages NIST to place a more balanced emphasis on some key disciplines that are currently underrepresented in the NIST research program. These include the seismic performance of infrastructure systems and non-structural elements as well as geotechnical engineering. ACEHR also encourages NIST to identify building research that has widest possible impact on seismic resiliency. There are many types of low-rise, residential and industrial structures with seismic vulnerabilities that have not been addressed at the same level of detail as other types of structures (i.e. high-rise and mid-rise commercial and residential structures and industrial and infrastructure-related facilities). These structure types are also some of the most prevalent elements of the nation's building stock. Giving priorities to these topics may necessitate cutting back on some other research areas that have previously received more attention in NIST-funded research.

The current NIST team, consisting of internal researchers augmented by their management of external research efforts, has the technical capability and experience to cover a wide range of important structural-related research areas, including steel and concrete systems, performance-based seismic design, nonlinear analysis methods and performance evaluation of existing buildings. It would be a natural extension of current capabilities to increase in-house and external research capabilities in the lifelines and geotechnical areas. The significant advancements in building science and engineering have been made through focused research and implemented into guidelines and standards to allow building owners to cost-effectively meet designated performance objectives. This is critical and essential progress for building structures which must continue. However, there are no similar developments for lifelines due to a lack of research focus and even less focus on developing basic tools, guidelines and standards to improve lifeline system performance. Furthermore, there is a limit to improving building and lifeline system performance if there is no equivalent understanding in the geotechnical aspects of the earthquake problem. In the community resilience context, it is important that all urban systems function as needed during and following an earthquake. This includes buildings as well as lifeline systems and geotechnical structures that serve the community.

E. National Science Foundation (NSF)

The NEHRP statutory responsibilities and strategic plan tasks assigned to NSF mainly relate to the agency's Engineering and Geosciences Directorates. Social, behavioral and economic science research related to NEHRP has been funded both through the Engineering Directorate and the Social, Behavioral and Economic Sciences Directorate (specifically the Division of Social and Economic Sciences). The research funded by NSF represents a combination of coordinated research programs and unsolicited proposals.

ACEHR commends the NSF for maintaining a strong external research program that continues to build basic and applied knowledge on earthquake hazards reduction along with a strong community of earthquake researchers, educators, and practitioners. The multi-disciplinary and cross-disciplinary research programs, including those supported through the earthquake and earthquake engineering research centers, and other NSF programs such as the Interdisciplinary Research in Hazards and Disasters (Hazard SEES) and Critical Resilient Interdependent Infrastructure Systems and Processes (CRISP) programs, accelerate the breakdown of disciplinary barriers, which in turn is facilitating the capacity to tackle multi-disciplinary problems such as assessing and planning for earthquake resilience. Furthermore, NSF's efforts to create shared research facilities, data repositories, and common simulation platforms, for example through the George E. Brown Network for Earthquake Engineering Simulation (NEES) program, have created increased access to research and are accelerating learning.

ACEHR is concerned, however, about the dissipation of focus within NSF on earthquake hazards with the development of multi-hazard program solicitations and the end of a number of earthquake engineering specific programs and emphases. Earthquake-related social science and policy research emphases often appears as an appendage to multi-disciplinary research projects. Also, large infrastructure programs such as the Seismological Facilities for the Advancement of Geosciences & EarthScope (SAGE), Geodesy for the Advancement of Geoscience & EarthScope (GAGE), and NEES need better plans and mechanisms for sustained support following initial funding phases.

Recommendation 1

ACEHR recommends NSF adopt alternative budgetary and reporting approaches that clarify how NSF directs funds in support of NEHRP activities.

NSF program officers have repeatedly reported to ACEHR that NSF does not have a budget line item for NEHRP but that it, instead, reports expenditures as they are made. This approach to accounting for the expenditure of NEHRP-related funds significantly hampers the abilities of other NEHRP agencies to coordinate with NSF-funded NEHRP activities. ACEHR notes that the NEHRP legislation requires NSF to work in conjunction with FEMA, NIST, and USGS to develop a comprehensive plan for earthquake engineering research. This required coordination cannot occur if the NEHRP agencies do not know how NSF plans to direct its NEHRP funding.

ACEHR believes the effectiveness of NSF in support of NEHRP could be improved by more proactively reporting specifically what programs it intends to support (ahead of their award) in order to fulfill its NEHRP mission. These programs should be coordinated with the other NEHRP agencies, as required by the legislation.

It is also unclear how much research focus NSF is putting on lifeline earthquake engineering. NSF noted the Resilient Infrastructure Processes and Systems Science (RIPS) program has lots of activity, but it is unclear how much funding is for lifeline earthquake engineering. NSF is encouraged to identify a specific amount of money to be designated to fund lifeline earthquake engineering research consistent with the needs identified in the *Earthquake-Resilient Lifelines NEHRP Research, Development, and Implementation Roadmap (NIST GCR 14-917-33)*.

Recommendation 2

ACEHR recommends NSF develop a mechanism for publicizing current NEHRP-related research and the findings from it.

The merit-based funding mechanism of NSF is consistent with its goal to support high-quality scientific research. The funded research naturally covers a broad range of disciplines and topics. However, it is challenging for the other NEHRP agencies and those in the broader research community to know the range and specific details of the various funded projects. This, in turn, inhibits coordination among the NEHRP agencies. More can and should be done to disseminate and publicize the past and current research activities. Searches of NSF awards are insufficient for this purpose. In particular, with the end of the NEES program, there needs to be a coordinated mechanism by which to assemble various NEHRP-funded projects for the purpose of learning about their activities. Some new mechanism, such as an annual NSF NEHRP funding awards workshop, needs to be created.

Recommendation 3

ACEHR recommends NSF report to ACEHR, as part of the next ACEHR review, the status of earthquake-related research and funding commitments for its part of the NHERI initiative.

A major engineering-focused activity of NSF over the past two decades has been the development, operations and research of the George E. Brown Network for Earthquake Engineering Simulation (NEES). Both the operations and the supported research programs under NEES are now in transition. A new solicitation for proposals to establish the Natural Hazards Engineering Research Infrastructure (NHERI) for 2015 - 2019 is intended to support a network coordination office, experimental facilities, cyberinfrastructure, and computational modeling and simulation tools for earthquake engineering and wind engineering research. The new emphasis on wind engineering will lead to improvements in the nation's resilience to natural disasters. However, NSF must ensure that earthquake-related research supported by NEHRP is not diminished by this new initiative.

Recommendation 4

ACEHR recommends NSF review lessons of multi-disciplinary hazard-related initiatives to assess the quality of cross-disciplinary, and especially social science, participation. At the same time NSF should continue and enhance investment in social science research related to hazards and disasters.

Recent NSF initiatives have emphasized social science contributions as part of multi-disciplinary, hazard-related undertakings such as the Interdisciplinary Research in Hazards and Disasters (Hazards SEES) and Critical Resilient Interdependent Infrastructure Systems and Processes (CRISP) solicitations. Social science contributions to such initiatives are essential for implementing advances in earthquake engineering. Too often the social science contributions appear as appendages to such projects. Yet, there is enough experience now with such initiatives to draw lessons and consider best practices.

At the same time, continued investment in social science funding under the NSF Infrastructure Management and Extreme Events and the Civil Infrastructure Systems programs is important for advancing progress on important socio-demographic changes and societal issues relating to seismic resilience for the built environment and infrastructure systems. ACEHR strongly encourages NSF to demonstrate that it is continuing support of NEHRP-related social science research.

F. United States Geological Survey (USGS)

ACEHR finds that the USGS continues to maintain a holistic program that encompasses all aspects of earthquake hazard - ranging from real-time seismic monitoring and reporting, millimeter-scale laboratory research, large-scale tectonic deformation modeling, to basic theoretical research on the earthquake process. All of these efforts produce data and understanding that is continually integrated to improve and upgrade the National, as well as local scale, earthquake likelihood and seismic hazard assessments and many other products the public depends upon. The USGS Earthquake Program is a healthy mix of fundamental and applied science with a healthy public communication and outreach component. The USGS has also worked well with NSF on several NEHRP-related efforts.

Some of the notable accomplishments by the USGS Earthquake Hazards Program in addressing NEHRP goals:

- Substantial expansion of seismic monitoring in the central and eastern United States through the adoption and upgrading of 160 EarthScope (N4) seismic stations. This conversion to permanent status of these previously "temporary array" stations was jointly funded by NSF and the USGS and represents an excellent example of NEHRP collaboration.
- Commitment to ongoing improvements in the National Seismic Hazard Maps which are created using an open, collaborative process. Maps are updated on a 6 year cycle designed to correspond to

updating of seismic criteria in the International Building Code. Input parameters for the maps are solicited in open regional workshops. Draft versions of the updated maps are posted online for public comment. This process insures that the input to the hazard model reflects state-of-art knowledge and is defendable.

- Demonstratively-responsive national earthquake monitoring, for example, their quick installation of additional seismic stations in Oklahoma which has been essential to evaluating the significance of recent and dramatic increases in seismicity in the state. These new stations were quickly integrated into the USGS national real-time seismic network. However, a lack of resources did not allow the USGS to investigate a recent increase of seismicity in Nevada.
- Conversion of the USGS global earthquake reporting center (National Earthquake Information Center, NEIC) in Golden, Colorado to 24/7 operations. This effort, supplemented with continued development of near real-time products such as ShakeMap, PAGER, etc., allows the USGS to keep the public informed about the occurrence, intensity of shaking, and likely impacts of significant earthquakes both within the US and globally within minutes of their occurrence.
- Initial implementation of a public earthquake early warning (EEW) system in California.
- Maintaining an extremely successful External Research program (representing 25% of overall program dollars) that is well focused and complements and fills gaps in the internal program. This represents a great leveraging of program dollars.
- Development of the Uniform California Earthquake Rupture Forecast (UCERF) in collaboration with the Southern California Earthquake Center which is used in helping set residential earthquake insurance rates and policy coverages in the State as well as many other earthquake hazards mitigation and preparedness planning efforts.

Despite this strong record of accomplishments, the USGS' Earthquake Program faces a number of challenges:

- Maintenance of seismic and other monitoring networks along with the required telemetry and analysis for real-time data delivery represents a significant capital cost that grows annually. Adding new stations, while expanding recording and detection capabilities, further increases these capital costs. To ensure a healthy, holistic program, the USGS must be mindful of the balance between monitoring and its research and assessment programmatic elements.
- Being judicious in what opportunities are committed to with the already overextended resources. For example, "operational earthquake forecasting" is currently getting a great deal of visibility within the scientific community. ACEHR is concerned that the small probability gains obtained through this methodology have not demonstrated significant usefulness for the public. It is likely that operational earthquake forecasting may take a substantial financial commitment over a long time period to see real public benefits. We feel that investment in operational earthquake forecasting investigations is probably not the best use of the agency’s limited resources at this time.
- Determining how much effort to invest in geodetic monitoring with the primary constraint that the effort makes an impact on hazard assessment.
- Paying attention to an aging workforce.
- Addressing the "implementation gap" with respect to the use of the National Seismic Hazard Maps by practicing engineers. Updating the seismic hazard input parameters to reflect the most current and best available science has sometimes resulted in back-and-forth swings in the seismic design values. These fluctuations can erode confidence in the seismic hazard estimates, and suggest that the hazard data is being incorporated into the design standards before it is sufficiently vetted and mature. This can be especially problematic if a jurisdiction were to tie mandatory seismic retrofits based on a structural analysis or shaking level. A building might go in and out of compliance every few years, based solely on changes to the maps. The current method of presenting the seismic

ground shaking data in very precise terms suggests a level of certainty the may be inappropriate from an engineering perspective. A presentation of seismic ground motion values with a degree of precision compatible with significant uncertainty involved in their determination would provide a better engineering solution. We commend the USGS for creating a new industry council to help address these and other issues, and see a need for practicing engineers who are the primary users of these products to participate on this council.

Recommendation 1

ACEHR recommends the USGS utilize the 160 new seismic monitoring stations obtained from NSF to collect strong motion data to better constrain the largest source of uncertainty in assessing seismic hazard in the central and eastern United States—how seismic shaking decays (attenuates) with distance from the earthquake source.

Far and away, the largest source of uncertainty in assessing seismic hazard in the central and eastern United States is the lack of knowledge about how seismic shaking decays (attenuates) with distance from the earthquake source. Ground motion attenuation relations are key inputs into seismic hazard assessments and are obtained by direct measurement of strong ground shaking in earthquakes through special sensors designed on scale.

The OMB and OSTP recently approved a joint USGS-NSF plan to convert 160 NSF-funded portable seismic stations in the central and eastern U.S. to permanent recording stations operated by the USGS. NSF is to fund the costs of inventory replacement, station upgrades, and operations and maintenance (O&M) costs through 2017. The USGS is also currently contributing to the O&M costs, and is seeking funding to operate the network beginning in 2018.

This newly expanded seismic network in the central and eastern U.S. with its dense and nearly uniform station coverage provides an unprecedented opportunity to both greatly increase USGS' ability to monitor even small earthquakes in the region, but also to capture the strong ground motion from even moderate earthquakes. Currently the USGS plans to only put strong motion sensors on 60 of the 160 new stations (those in highest hazard regions). Since earthquakes occur randomly throughout this region (e.g., the 2011 Mineral, Virginia earthquake) and seismicity is increasing throughout the region due to oil and gas production, there is a great opportunity to get the required strong motion data which would be extremely valuable not only for improving design codes but also for seismic safety analysis of the approximately 70 nuclear power plant sites in the central and eastern United States. Adding the requisite sensors to the additional 100 stations would be a modest capital cost and would add only very modestly to the operational and maintenance costs. Perhaps a partnership with the Nuclear Regulatory Commission could help cover the capital costs.

Recommendation 2

ACEHR recommends that the USGS make Earthquake Early Warning (EEW) a funding priority for NEHRP. In order to develop, implement, and operate an earthquake early warning system for all seismically active regions in the United States additional federal funding will be required.

Earthquake Early Warning (EEW) was one of the capabilities described in the 1999 USGS plan, *Requirement for an Advanced National Seismic System*, (USGS Circular 1188) but significant shortfalls in funding for this plan delayed its implementation. However, the USGS is now fully committed to this emerging technology and has appointed a national coordinator for the development and implementation of an EEW system for the West Coast of the U.S., with the long-term goal of extending the system to all seismically active regions in the country. While the technology to provide warning of impending ground shaking from an earthquake is reasonably mature (a nationwide EEW system was implemented in Japan in 2007), funding for expanding and upgrading the seismic networks in Washington, Oregon and California (prerequisite for a reliable, robust and timely EEW system), and operating such a system, is not assured.

Thus far, the USGS and participating universities and state government partners have obtained grants from a private foundation and limited federal funding, but no assurance of sufficient support for the needed seismic network upgrade, nor operating funds to run an EEW system along the West Coast.

In 2013, California passed legislation mandating the development and implementation of an earthquake early warning system for the State, but included a provision indicating that funding for the system could not come from the State's General Fund. Currently, there are five state-appointed committees—including one dedicated to the identification of funding strategies—working on an implementation plan for EEW in California. The estimated operating cost for only California and the Pacific Northwest is $17 million/per year — in addition to the current monitoring budget. The current annual budget for all of the USGS Earthquake Program is about $55 million per year, with about $26 million per year dedicated to earthquake monitoring. Thus, an operational EEW cannot be a program that comes from the base budget of the USGS Earthquake Program. EEW requires separate, long-term funding that does not degrade the USGS' overall mission to understand and mitigate earthquake hazards.

One model being considered for EEW system funding is a subscription service in which users would pay a fee for access. ACEHR cautions, however, that geologic hazard warnings are a public good and should be available to all regardless of the ability to pay.

Recommendation 3

ACEHR recommends the USGS continue efforts to expand the understanding of the hazard posed by induced seismicity.

ACEHR concurs with the recommendations of the USGS's National Seismic Hazard and Risk Steering Committee that the USGS should develop short-term hazard products for induced seismic activity, which might be updated annually. We further recommend that in developing these products that the USGS convene a focus group of local and state stakeholders to determine which types of products would be the most useful.

A recent upswing in oil and gas production, particularly in the central and eastern United States, has raised concerns about triggered or "induced" seismicity related to injection of waste water generated by this (and other industrial) activity. Furthermore, work is also beginning throughout the central and eastern U.S. on pilot projects investigating large-scale underground injection and permanent storage (sequestration) of CO_2. In support of the Administration's "all of the above energy strategy," the USGS received $1.8 million in FY14 to expand its study of induced seismicity. In FY15, Congress increased funding to $2.5 million in support of research to better understand factors controlling induced seismicity and how to best assess the related seismic hazards.

ACEHR has identified three significant opportunities and challenges for NEHRP related to seismicity induced by subsurface injection of waste water/fluids, including CO_2:

- Quantify the seismic risks to neighboring communities posed by injection-induced seismicity (from oil and gas activities, CO_2 sequestration, or enhanced geothermal production).
- Determine how induced seismicity impacts the “tectonic based” USGS National Seismic Hazard maps and how the effects might be incorporated in some time-dependent assessment of seismic hazard.
- Take advantage of select injection sites as opportunities to better understand the relationship between seismicity and injection pressures, and collect new ground motion data to better constrain seismic attenuation in the central and eastern United States; the largest uncertainty in producing seismic hazard maps for these regions.

As noted above, the USGS is in the process of greatly expanding their seismic network coverage in the central and eastern United States. The newly enhanced USGS central and eastern U.S. seismic network will now have a uniform detection for earthquakes as small as magnitude 2.5.

In order to make progress on understanding the occurrence of induced seismicity, USGS researchers need access to injection data (e.g. volumes, rates, pressures), in addition to the more extensive seismic observations. These data are often considered proprietary, although some of information is required to be released to the States. The USGS is currently partnering with a wide range of federal, state, university, private and international institutions in its efforts to better constrain induced seismicity and its effects. One of these partnerships, with DOE and Archer Daniels Midland, resulted in the USGS installing surface and borehole seismic monitoring at the Decatur, Illinois CO_2 sequestration site. Preliminary results suggest that CO_2 injection is inducing micro-earthquakes probably on pre-existing, well-oriented faults. Many more such studies with both detailed seismicity and injection time history data are needed.

Finally, with regard to the impact of induced seismicity on seismic hazard, there are many uncertainties. For example, the dynamics of the subsurface hydrologic process is not well understood and difficult to model confidently. In response to the 2013 ACEHR recommendation calling for more research to evaluate the impact of induced seismicity on seismicity rate models and how the hazard can best be represented, the USGS convened a National Seismic Hazard and Risk Steering Committee. Their report was submitted to the USGS on November 25, 2014. This committee endorsed several alternative ways proposed by the USGS’ National Seismic Hazard Map team to capture the short-term hazard associated with induced seismicity. The Committee recommended that the products representing the hazard of induced seismicity be based on the seismic activity of a relatively short time interval (e. g., the prior year), and be presented in new ways that are appropriate for various users, with the emphasis that they are only applicable for a relatively short duration (e.g., the subsequent year). They also recommended that the USGS provide annual updates to these special induced seismicity hazard products.

Recommendation 4

ACEHR recommends the USGS expand earthquake scenario development in conjunction with stakeholder engagement in order to examine consequences of earthquakes in particular urban areas.

The development of earthquake scenarios in conjunction with key stakeholders (including local government, utility operators, emergency responders, etc.) has helped to stimulate mitigation action. For example, the 2008 ShakeOut scenario for a major earthquake on the southern San Andreas fault has led to the "Resilience by Design" seismic program announced by Los Angeles' mayor office in December 2014.

Recommendation 5

ACEHR recommends the USGS improve seismic instrumentation sites with infrastructure/lifeline systems to integrate the seismic information needed and provide near real-time intelligence for operators to understand system impacts from shaking ground movement (e.g., fault rupture, after slip, etc.). This development can be used to further enhance the EEW program.

ACEHR encourages the USGS to explore joint funding models with infrastructure/lifeline operators for the purchase and maintenance of seismic instrumentation that can also be tied into both the operators' and USGS strong motion network. There is substantial value added by combining strong motion data in real-time with the USGS' existing network. ACEHR also recommends that the USGS work closely with infrastructure/lifeline system owners and operators for developing and implementing EEW systems—a priority topic identified in the NIST consistent with priorities research identified in the *Earthquake-Resilient Lifelines NEHRP Research, Development, and Implementation Roadmap (NIST GCR 14-917-33)*.

Appendix – Emerging Trends and New Developments

ACEHR is charged to report on new trends and developments related to NEHRP. Time constraints and the size of the Committee do not permit this to be an exhaustive treatment of the topic, though the Committee's unique composition does permit an expert-based overview. The presentation that follows is organized around the key disciplines that form the earthquake professions and should serve to provide a concise picture of the possible future. Included are both suggested refinements to tasks in the 2009–2013 NEHRP strategic plan and new tasks that should be considered for future plans.

A. Social Sciences

The diversity of social science research—drawing from economics, land use planning, political science, public administration, public health, public policy and sociology—has provided a rich understanding of a range of topics concerning emergency response, disaster impacts and recovery, hazard adaptation and mitigation, and the vulnerability of different populations to extreme events. These are important research topics that warrant continued funding. Historically, much of this research has been funded by the National Science Foundation through the Infrastructure and Extreme Events and Civil Infrastructure Systems programs in the Engineering Directorate, and the Decision, Risk, and Management Sciences Program in the Social, Behavioral and Economic Sciences Directorate.
Three trends stand out in recent social science funding and research.

The Diversification of Funding within the National Science Foundation

This diversification is evident in the launch of a number of larger-scale, interdisciplinary hazard-related initiatives that include social science contributions. These include current funding under the Interdisciplinary Research in Hazards and Disasters (Hazard SEES) and Critical Resilient Interdependent Infrastructure Systems and Processes (CRISP) programs, prior funding under the Human Systems Dynamics (HSD) Program and the Earthquake Engineering Research Centers, and NSF collaborative funding efforts with the Department of Agriculture and the National Oceanic and Atmospheric Administration. This trend is positive in injecting new funds and bolder undertakings that place social science contributions on stronger footing. Yet, issues remain concerning integration of the social sciences so that the contributions are not merely appendages to such projects. As well, the diversification of these funding sources makes it difficult to track the amount of funds that go to social science, hazard-related research.

A Shift in Research Emphasizing Community and Societal Resilience

A second trend is a shift in research emphasizing community and societal resilience in keeping with the NEHRP strategic plan and broader national-level initiatives. In recent years, social science researchers have developed frameworks for measuring community resilience, expanded assessments of vulnerability, considered factors that foster and limit community resilience, and examined the economic aspects of interdependencies in decision-making for protective actions. Each of these topics deserves further attention with a continued need for a more comprehensive resiliency and vulnerability observatory network. Gaps remain in the understanding of mechanisms for gaining private and public sector commitment for resilient infrastructures, the coordination of public and private actions at different levels of government in advancing community and societal resilience, and the prevention and response to cascading disruptions across interdependent infrastructures.

Moreover, research is needed on both areas where populations wide recognize high earthquake hazard levels (e.g. California) and places with long-standing but less recognized seismic threats as well as emergent threats due to increased seismicity in response to industrial activity.

Continued Investment by NSF in Advancing Human Capital for Social Science Research

A third trend is the continued investment by NSF in advancing human capital for social science research contributions. Two initiatives have been undertaken that go beyond support for graduate students and post-doctoral researchers as part of NSF-funded projects. One was the funding of graduate dissertation research scholarships for hazard-related research. A second is funding for a fourth round of the Enabling Program for the Next Generation of Hazards Researchers. This is aimed at recruitment, mentoring and training of emerging social science scholars as a means expanding and diversifying the pool of researchers. This has been an important program for confronting a generational change in the talent pool and for responding to new trends in research issues.

B. Earth Sciences

This section addresses aspects of earthquake seismology, strong-motion seismology, and developments in associated programs relevant to NEHRP. The knowledge, tools, and practices in this arena overlap science and engineering—especially relating to design ground motions, where scientists and engineers work closely together. They also overlap science and emergency management.

Analyzing Induced Seismicity

In the two years since ACEHR's last report, the pattern of earthquakes affecting the population has changed significantly with the large number of felt and minor damaging earthquakes in Oklahoma, Kansas and Texas. While these earthquakes may be associated with industrial activity, the precise mechanism for their occurrence is not well known. The determination of the location, size and type of faulting of these earthquakes has improved because of collaboration among universities, state and federal agencies in the operation of seismic stations in proximity of the earthquakes. One hundred and sixty stations of the NSF EarthScope Transportable Array are being transferred to the USGS by 2017. These stations located in the central and Eastern U.S. will improve the ability of the USGS to locate and assign magnitudes to these earthquakes. The magnitudes, rates of occurrence and locations are used for hazard mapping by federal and state regulatory agencies.

Seismic Monitoring

The issues of seismic monitoring and associated data preservation must be addressed. Under current funding guidelines, the USGS recently approved 5-year cooperative agreements for regional seismic networks in Alaska and the western United States, but only 3-year agreements for the networks in the eastern U.S. because of funding uncertainty given that it must also take on the 160 stations of the NSF EarthScope Transportable Array in 2017. Stable monitoring is required to maintain and improve a system fundamental to emergency response and long-term research.

Archiving Seismic Data

While the quality of the seismic data meets standards imposed by the network operators, there is a fundamental requirement that the data be curated, archived and made accessible in perpetuity. NSF must continue to support the archiving infrastructure so that the data can be used to improve our understanding of earthquake hazards and methods for mitigating their effects.

Development of an Earthquake Early Warning System

An Earthquake Early-Warning (EEW) system is a primary product resulting from a fully developed advanced national seismic system (ANSS). The infrastructure for an EEW system is being developed in California and the Pacific Northwest. The requirements for the infrastructure in other regions of the U.S. have to be developed. When implemented, this system will be a major advance in providing critical warning time prior to severe shaking. In addition, significant progress has been made in creating a national earthquake monitoring system that serves the purposes of immediate notification as well as long-term hazard assessment. The challenge is to maintain and improve such a system so that the effects of earthquakes anywhere in the U.S. and its territories can be better anticipated and managed in real-time.

Application of Digital Imaging Technologies for Fault Mapping

Recent developments in airborne and terrestrial digital imaging methods such as Light Detection and Ranging (LiDAR) technology have enabled rapid and remote identification of subtle fault scarps and faulted materials at scales varying from a few meters to regional. These methods have led to more accurate and more extensive mapping of active fault traces in urban and non-urban areas.

C. **Geotechnical Earthquake Engineering**

Geotechnical earthquake engineering covers earthen structures and closely interfaces with the disciplines of earth science, structural engineering, and lifeline engineering and in general it affects all earthquake engineering-related disciplines. Advances in community seismic resilience can be achieved only if design, construction, and infrastructure operations account for the geotechnical effects of earthquakes, including surface fault ruptures, seismic site effects, liquefaction, seismic instability, and soil- foundation-structure interaction. As the criticality of a multidisciplinary approach to addressing earthquake hazards (as well as other hazards) is recognized, geotechnical engineering as a natural linkage between disciplines can provide a critical path forward to improving seismic resilience.

Liquefaction in Recent Earthquakes

Recent earthquakes, including the 2011 Tohoku earthquake in Japan and the 2010-2011 Canterbury earthquake sequence effecting Christchurch, New Zealand, have shown the important effects of earthquake-induced liquefaction on buildings, especially residential structures, and on lifeline systems, including water and wastewater distribution systems, underground electric power cables, and highway bridges. Of particular importance is the experience gained from the Tohoku earthquake, which shows that the incorporation of stiff mat or grade beam foundations has been effective in protecting residential structures from the effects of liquefaction. Highly ductile lifelines in Christchurch, composed of high- or medium-density polyethylene pipelines, have also been able to accommodate large ground deformations with lateral displacements of 3 to 5 feet. Similarly, the Japanese earthquake resistant ductile iron pipes have been used for over 40 years and shown to accommodate large ground movements exceeding 9 feet without damage.

Integration of Geotechnical Engineering and Earth Science

Earthquake science and engineering should grow more interconnected and interdisciplinary and NEHRP should support this interaction. Geotechnical engineering needs to be an integral part of multidisciplinary seismic research. Although NIST's establishment of an extramural applied-research program fills a critical gap between NSF-funded basic research and the implementation of earthquake risk-reduction measures, the NIST program should include the effective transfer of geotechnical engineering knowledge.

Multihazard Considerations in Geotechnical Engineering

Geotechnical earthquake engineering addresses numerous multihazard aspects from liquefaction induced ground deformations and impacts on other engineered facilities to increases in flood risk following an earthquake. The impacts on common water retaining geotechnical structures such as dams and levees result in deformations and loss of hydraulic capacity which is needed for community protection within months following an earthquake. The geotechnical related ground deformations across an urban region often result in increased risk of inundation. The Wenchuan China, Tohoku Japan, and Christchurch, NZ regions have on-going flood problems as a direct result of geotechnical earthquake mechanisms. The broader goal of community resilience requires these geotechnical-related multihazard issues be addressed. As an example, levee and flood protection system reliability, including their seismic performance, must be addressed and measures taken to strengthen critical flood protection systems. Resilience can be achieved through the use of innovative mitigation techniques, such as those for liquefaction. Additionally, geotechnical-earthquake problems need to be considered as part of city-wide land use planning in advance of allowing development.

Predicting Liquefaction

Of particular importance is the improvement of methods that both predict the occurrence of liquefaction and provide estimates of the settlement and lateral ground movement resulting from liquefaction. It has been well over a decade since consensus guidelines for evaluating the potential for liquefaction and its consequences have been reviewed by the geotechnical community. Several major earthquakes have occurred and been investigated, resulting in substantial new data on liquefaction behavior. The new data on liquefaction and its effects on lifeline systems and buildings need to be reviewed, and the next generation of consensus procedures for predicting and accounting for the consequences of liquefaction need to be developed.

Hazard Maps for Ground Failure

Improved hazard maps for ground failure and methods for characterizing the magnitude and distribution of ground movements triggered by earthquakes are needed for land use planning as well as the proper siting, design, and rehabilitation of infrastructure and structures. Better methods are needed for predicting liquefaction impact on geographically distributed systems. The triggering of liquefaction or ground softening in silty and clayey soils requires greater understanding, and engineers require improved tools for evaluating the consequences of liquefaction. Robust analytical procedures have been developed for predicting ground deformation and characterizing structural response to ground movements. Research facilities, such as NEES, can be employed to clarify ground movement and soil-structure interaction for practical purposes. In particular, the profession lacks clear guidance on the potential impact of soil-structure interaction on building performance and of soil-water-structure interaction on earth dam and levee performance.

New Computational Tools and Data Archiving

High-end computing coupled with enhanced visualization software is transforming the manner in which we evaluate seismic performance. Practicing engineers require critical assessments of these sophisticated computational tools to ensure that reliable results are produced. Realistic modeling of earth particles, interfaces, and discontinuities remains an important need. Supporting efforts need to continue toward characterization of geo- material properties and the uncertainty inherent in any seismic problem. Field and laboratory experiments are required to advance earthquake science and engineering through innovative site and material characterization technologies. The geotechnical information collected following earthquakes should be archived as well and made available to researchers, engineers, planners, and emergency responders. Incorporation of advanced technologies and imaging techniques, such as Light Detection and Ranging (LiDAR), in post-earthquake reconnaissance can strengthen the lessons that the profession can glean from future earthquakes.

Tools for Performance Based Design

Performance-based earthquake engineering requires consensus methods for selecting and scaling ground motions to represent the seismic hazard at a project site and quantitative data that translates calculated engineering responses into damage and then deaths, dollars, and downtime. Without full implementation of ANSS, the spatial variability of ground shaking due to local geology cannot be refined or utilized optimally in post-earthquake emergency response. Geotechnical structures, including downhole arrays, should be better instrumented. Improved models of ground shaking near faults and in the eastern and central United States are required. The seismic response of IBC 2006 Site F soils requires better characterization. Owners should be motivated to better understand the special nature and needs of their project and engage engineers to design for the desired level of performance according to a site-specific hazard assessment. While NEHRP should advance building codes, the program should also advance tools that move the profession toward true performance-based design.

D. Structural Earthquake Engineering

New trends and developments in structural earthquake engineering can take multiple forms including advanced research, development of new codes and standards, and related activities in the structural earthquake engineering design community. Current earthquake engineering research is wide ranging and covers a myriad of structural and non-structural topics. NEHRP agencies, primarily FEMA, NIST and NSF, are typically major supporters of this research in the United States. While it would be a major endeavor to cover all current research trends, it should be noted that significant research is being conducted related to structural and non-structural issues that is intended to provide options for improving the resilience of facilities after a major seismic event.

New Building Codes and Standards

In the structural engineering community at large, new trends and developments are typically disseminated through the issuance and implementation of new codes and standards. ASCE 7, which is the primary structural reference in the *International Building Code (IBC)*, is the most widely utilized standard in the structural engineering community in the U.S. that relies on the NEHRP Recommended

Seismic Provisions for its technical underpinnings. Significant changes in the seismic provisions, such as the issuance of revised ground motion maps (developed and issued by the USGS, a NEHRP agency), are first encountered by most structural engineers through ASCE 7.

Guidance for Seismic Evaluation of New and Existing Buildings

A recent milestone in the structural earthquake engineering community was the issuance of the revised ASCE 41 Standard, *Seismic, Evaluation and Retrofit of Existing Buildings*. This standard is a widely-referenced document for the seismic evaluation and retrofit of existing buildings, and its detailed information is also utilized in Performance-Based Seismic Design (PBSD) of new buildings. There are many other initiatives underway which examine specific issues and elements affecting seismic performance. A recent example is NIST GCR 12-917-20 *Tentative Framework for Development of Advanced Seismic Design Criteria for New Buildings*, which was prepared for NIST under the NEHRP program. This document examines seismic performance factors with the objective of updating these factors for inclusion in future versions of seismic design codes.

Knowledge Transfer through Local Associations

As noted above, the majority of practicing structural engineers are typically reactive with respect to the new or updated seismic analysis and design requirements in the current codes and standards. However, it should be noted that many structural engineers who are not directly involved with research and/or the codes and standards process are active in their local associations or organizations that focus on structural and earthquake engineering. It is through these organizations and associations that many structural engineers advocate for stronger seismic codes, more advanced licensure requirements and better implementation of seismic design requirements as projects move through construction.

Code Adoption, Quality Assurance and Enforcement

The primary means of achieving resiliency in communities that are subject to earthquake risk is through the adoption and enforcement of modern building codes, but there are barriers to successful implementation of these codes. Truly effective seismic design of structures rests on three interdependent factors. The first is the use of modern, up-to-date codes and standards. Many communities do not adopt the latest edition of the code and may keep the same edition of the code in force for decades. The seismic provisions of the earlier editions of the building code may be unconservative - in some cases significantly unconservative. The second and third factors relate to enforcement of the codes. Even if current codes are adopted, they are ineffective unless properly enforced. Enforcement begins with an examination of the plans for the structural design by qualified individuals. Review of the plans during the permitting process can reduce the likelihood that design errors will impact the performance of the structure. Finally, the best of designs is of little value if the structure is not built in accordance with plans. Quality assurance programs during construction are critical to good seismic performance. Quality assurance programs often do not include anchorage and bracing of nonstructural components, items that account for the vast majority of damage and losses in past earthquakes.

Many communities lack the resources or the political will to enforce the codes they have, especially the seismic provisions in areas that have not experienced a strong earthquake in recent years. Education and outreach are needed to train and inform the code enforcement community on the proper interpretation and application of the seismic design provisions. Design professionals and contractors also need to be kept up to date on seismic requirements; especially in regions where earthquake resistant design has not been practiced in the past.

E. Lifelines Earthquake Engineering

Lifelines provide the networks for delivering resources and services necessary for the economic well-being and security of modern communities. Historically they have been grouped into six principal system types: electric power, gas and liquid fuels, telecommunications, transportation, wastewater and water supply. In the past decade there have been a number of events identifying the need to pay more attention to inundation protection systems as lifelines. The most notable of these events include 2005 Hurricane Katrina, 2011 Tohoku Japan Earthquake and the 2010-2011 Canterbury, New Zealand earthquake sequence. Inundation protection systems include the regional systems of levees, floodwalls, sea walls and other systems to protect infrastructure from flooding. These and other events also highlight the need to include solid waste management as a lifeline. Taken individually, or in aggregate, lifeline systems are essential for emergency response and restoration after an earthquake, and are indispensable for community resilience.

Learning from Recent Earthquakes

Hurricane Sandy and concerns about the future impacts from climate change have drawn significant attention to the need for more resilient communities for all types of hazards in the United States. Significant events abroad including the 2011 Tohoku Japan Earthquake and the 2010-2011 Canterbury, New Zealand earthquake sequence remind us how devastating earthquakes can be to our communities. Japan and New Zealand are struggling with issues on how to make their cities more resilient while rebuilding after the devastation, all the while managing the serious economic impacts from the earthquake and cascading multi-hazard strikes (including tsunami and liquefaction). In all cases, lifeline performances are found essential for resilient communities.

Lifeline Related Security Measures

Since 2001, lifelines have received increasing attention through the Department of Homeland Security with respect to national security. The National Infrastructure Protection Plan includes 18 different sectors of critical infrastructure that include or are directly related to the lifeline systems traditionally studied under NEHRP. These initial efforts were enhanced by Presidential Policy Directive 21 (PPD21) *Critical Infrastructure Security and Resilience* in 2013 in an attempt to improve resilient lifeline performance when earthquakes or other severe hazards strike. Emphasis has been placed on the development of high-performance computational models that simulate the regional response of complex networks and their interdependencies. Communications and electric power have been identified as especially critical due to reliance of other systems on their functioning. Following PPD21, NSF has funded research on Resilient Infrastructure Processes and Systems (RIPS). NSF has other research programs in which lifeline systems may be integrated, including geotechnical and lifelines research for the New Zealand and Japan earthquakes.

Community Disaster Resilience Program

NIST is undertaking a Community Disaster Resilience Program, within which they will convene a panel on disaster-resilience standards to develop comprehensive, community-based resilience planning guidelines for consistently safe buildings and infrastructure – products that can inform the development of private-sector standards and codes. This approach was included in the President’s Climate Change

Action Plan. NIST has also prepared a roadmap for a research, development and implementation program for NEHRP activities to improve lifeline earthquake resilience (NIST GCR 14-917-33). A project was recently initiated for NIST as a direct result of recommendations in NIST GCR 14-917-33 to address lifeline system performance criteria needed to support community resilience.

Scenarios Including Lifeline Impacts

The USGS has emphasized the complex interactions of lifeline systems and impacts on community resilience through scenario events. For example, the Great Southern California ShakeOut of 2008, which at that time was the largest earthquake preparedness drill in U.S. history, examined the consequences of a magnitude 7.8 earthquake on the southern San Andreas Fault through a variety of computational models and included all regional lifeline systems. This scenario evaluation identified a number of critical lifelines-related issues needing to be addressed to improve Southern California seismic resilience. Dr. Lucy Jones of the USGS became a science advisor for the mayor of Los Angeles for the 2014 calendar year, which resulted in the mayor releasing the *Resilience by Design* report, having many significant resilience recommendations for buildings, water, power and communication systems, and with a special emphasis on addressing fire-following-earthquake hazards.

These developments, driven by NEHRP agencies, show continuing progress in improving the earthquake resilience of lifeline systems. There are also common trends revealed related to multi-hazards, dependency relationships and how lifelines are critical to supporting community resilience. Similar and related industry trends are exemplified by the American Society of Civil Engineers creating the Infrastructure Resilience Division with a mission to advance civil infrastructure and lifeline systems for local, regional and national resilience against all hazards.

Performance Standards for Lifelines

Unfortunately, even with continued progress in lifeline earthquake engineering, there is an absence of unified or even loosely-coupled performance standards for lifelines. Clear expectations for emergency services and plans for the coordinated response of different lifeline systems are generally absent. Levels of vulnerability are unnecessarily high and the ability to recover from extreme events is much less effective than most communities recognize. As a result, there remain significant needs in this area, many of which are identified in the NIST GCR 14-917-33 document.

F. Disaster Warning, Response, and Recovery

The ultimate test of advances in earth science, engineering and social science is in their application and implementation in communities with significant seismic risk. Emergency managers are key functionaries in this process and significantly shape the manner in which new technologies and research findings are applied in warning the public of hazards, responding to significant events and implementing recovery programs that increase resilience to future hazards. Knowledge transfer, outreach and education are key components in this process.

Teaching the Public to Use Early Warnings for Earthquakes

By far, the most promising new technology in disaster warning is earthquake early warning, now in a beta testing phase in California. The ability to provide a few seconds to a few tens of seconds warning to a population prior to the arrival of potentially damaging ground motion has enormous potential in saving lives and reducing impacts on buildings and infrastructure. The most significant challenge is not intrinsic to the technology which is quite mature, but in securing funding to support enhancement of the seismic network to facilitate warnings, for ongoing maintenance and operation of an early warning system, and for the education and training of users to take full advantage of early warnings.

Reenergizing FEMA's Role in Implementation

FEMA, as the primary federal agency charged with responding to natural and man-made disasters, has successfully performed its responsibility in recent years. They have responded to numerous floods, hurricanes, tornados, wildfires and a variety of other disasters. However, their ability to successfully respond to a major earthquake has not been tested in over 10 years. During this period, as is documented in other sections of this report, both financial and technical support to State and local partners steadily decreased. With some exceptions, this decrease in support, logically translates in a decrease in capabilities to respond to a major earthquake. While response functions for most disasters are interchangeable, an earthquake response requires some unique capabilities. For example, the determinations of the safety, habitability and use of buildings and infrastructure impacted by an earthquake require significant engineering and architectural capabilities. The Committee is concerned that these capabilities have eroded or are not being developed because of a lack of funding and leadership. The Committee recommends that an evaluation of state capabilities, and perhaps selected local capabilities, be initiated.

Response to Large Earthquakes

FEMA, in cooperation with the states of Washington, Oregon and California and the Canadian Province of British Columbia completed a Cascadia Catastrophic Earthquake and Tsunami Response Plan in 2013 which will guide response to a large and possibly tsunami-genic earthquake in the Pacific Northwest along the Cascadia Subduction Zone. This plan and the scenario-driven exercises based on the plan address a significant vulnerability in the region. This plan is the third such plan developed with FEMA support. The others are response plans for a large southern California earthquake on the San Andreas Fault and a similar earthquake in the San Francisco Bay Area.

Considering the Complexity and Costs Associated with Recovery and Rebuilding following a Major Urban Earthquake

In 2011, FEMA released the National Disaster Recovery Framework providing a first-time, federal articulation of policy and direction on long-term recovery and reconstruction. The impetus for its development emerged in the aftermath of Hurricane Katrina in which the federal government invested over $100 million in recovery and rebuilding, and which included the largest publicly-financed housing repair programs in U.S. history in Louisiana and Mississippi. A large damaging urban earthquake in California, the Pacific Northwest, or the central and eastern U.S. could cause far greater life loss, economic disruption and rebuilding challenges and costs than what was experienced in 2005 Hurricane Katrina or 2012 Hurricane Sandy. In particular, today, less than 10% of California homeowners have earthquake insurance and post-earthquake housing needs, both interim and long-term, will be immense especially in tight and expensive housing markets in the Los Angeles and San Francisco regions for example.

There will be significant demands for federal funding for rebuilding and for NEHRP agency involvement in recovery, funding research and investigations into hazard and damage assessments and developing appropriate and effective mitigation and rebuilding solutions. It has been more than 20 years since we have experienced a major urban earthquake in the U.S., and the Committee is concerned that the ICC, NEHRP program officers and staff, as well as key federal agencies lack the hands-on expertise and real-life understanding of the complex nature of earthquakes and their consequences and the essential role that the federal government has provided in past earthquakes, such as funding large-scale ground deformation and steel-frame building damage investigations and mitigations.